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Peyman Milanfar

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Electrical Engineering Department
University of California
Santa Cruz, CA 95064

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Air Force Office of Scientific Research (AFOSR/NE)
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875 North Randolph Street
Suite 325 Room 3112
Arlington, Virginia 22203

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14. ABSTRACT

This research program is aimed at developing a broad suite of techniques in detection, estimation, and reconstruction from images and video, which will help to advance the state of the art in automatic target recognition.

15. SUBJECT TERMS

Statistical signal processing, detection, estimation, regression, motion, registration, fusion, superresolution, performance bounds

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Final Report

Detection and Discrimination at the Intersection of Statistical Signal Processing and Machine Learning

AFOSR grant F49620-03-1-0387,
Final Report for Sept. 2003 – March 2008

Principal Investigator: Peyman Milanfar
Department of Electrical Engineering
University of California
Santa Cruz, CA, 95064

1. Objectives

This program was intended to develop a broad range of algorithms in detection, estimation, and reconstruction from images and video, in support of advancement of the state of the art in automatic target recognition. In particular, the program addresses the following ten specific areas:

1. Development of novel signal detection and estimation strategies that
    a. extend classical signal processing approaches where distributions of the underlying data are partially known (e.g. GLRT), to the case where training data is also available for one or more classes.
    b. design robust discrimination functions (detectors), when a *sparse* set of training data is available for one or more hypothesis classes
    c. design sparse detection and estimation algorithms where the form or structure of the detector is fixed
    d. nonparametric kernel density and regression methods for signal denoising, interpolation, and approximation with applications to image reconstruction and nonparametric decision-making
2. Development of a statistical theory of resolution and its enhancement in signals and images within the context of estimation, detection and discrimination.
3. Application of the above theory to the design and analysis of imaging systems, as typically encountered in ATR applications.
4. Applications of the above theory to image analysis and to high resolution spectrum analysis.
5. Advanced motion estimation algorithms for scenarios where the captured images are known to be under-sampled or aliased.
6. State of the art algorithm development for the problem of super-resolution (including image fusion and deconvolution) where multiple aliased, noisy, low-resolution frames are integrated to produce a high-resolution frame.
7. Development of statistical performance limits for the problems above (5,6).
8. Development of novel analytical and numerical techniques and tools for image reconstruction based on the L_1 norm and generalizations of the total variation formulation to multiple scales.
9. Analysis of resolution, its enhancement, and its limits, in the context of active imaging systems.
10. Development and dissemination of software packages in support of the above program objectives.

2. Status of Effort and Accomplishments

In the past 4 and half years, we made significant progress (as described below) on all aspects of the program. The work during the course of the project culminated in 27 major journal publications, and 26 conference publications. Our accomplishments included the following:

- We published, for the first time, a unified statistical framework for measurement and analysis of resolution in signals and images based on concepts from the theory of locally optimal decision theory.

As resolution typically refers to the ability to distinguish closely spaced "events" (in either real space, time, or in some relevant feature space), the application of techniques from the local theory of hypothesis testing is a natural, but hitherto unexplored, area of research. The results of the analysis in this area have been extended to study the performance limits for the problem of spectral estimation. Our results have shown that the popular subspace-based methods in wide use in array processing can be significantly improved. This can be done by application of a "post-processing" detector which will analyze the local neighborhood of a candidate spectral, and explore whether two or more spectral components contributed to the locally measured energy.

- Super-resolution reconstruction produces one or a set of high-resolution images from a set of low-resolution images. In the last two decades, a variety of super-resolution methods have been proposed. These methods are usually very sensitive to their assumed model of data and noise, which limits their utility. In a paper that has been very highly cited in the last 3 years, we addressed these shortcomings. We proposed an alternate approach using L1 norm minimization and robust regularization based on a bilateral prior to deal with different data and noise models. This computationally inexpensive method is robust to errors in motion and blur estimation, and results in images with sharp edges. Simulation results confirmed the effectiveness of our method and demonstrated its superiority to other super-resolution methods. The resulting algorithm and several other competing algorithms was coded up into a Matlab-based software package and distributed to the academic community. This package has been widely used, resulting in a rapid acceleration of progress in this area of research worldwide.

- In the last two decades, two related categories of problems have been studied independently in the image restoration literature: super-resolution and demosaicing. A closer look at these problems reveals the relation between them, and as conventional color digital cameras suffer from both low-spatial resolution and color-filtering, it is reasonable to address them in a unified context. We proposed a fast and robust hybrid method of super-resolution and demosaicing, based on a MAP estimation technique by minimizing a multi-term cost function. The L1 norm is used for measuring the difference between the projected estimate of the high-resolution image and each low-resolution image, removing outliers in the data and errors due to possibly inaccurate motion estimation. Bilateral regularization is used for spatially regularizing the luminance component, resulting in sharp edges and forcing interpolation along the edges and not across them. Simultaneously, Tikhonov regularization is used to smooth the chrominance components. Finally, an additional regularization term is used to force similar edge location and orientation in different color channels. We show that the minimization of the total cost function is relatively easy and fast. Experimental results on synthetic and real data sets confirmed the effectiveness of our method.

- The concept of prior probability for signals plays a key role in the successful solution of many inverse problems. Much of the literature on this topic can be divided between analysis-based and synthesis-based priors. Analysis-based priors assign probability to a signal through various forward measurements of it, while synthesis-based priors seek a reconstruction of the signal as a combination of atom signals. In our recent work in collaboration with Dr. Michael Elad of the Technion, Israel Institure of Technology, we describe these two prior classes, focusing on the distinction between them. We have shown that although when reducing to the complete and under-complete formulations the two become equivalent, in their more interesting over-complete formulation the two types depart. Focusing on the denoising case using the l_1 norm, we derived a novel analysis approach for comparing the two types of priors, based on high-dimensional polytope geometry. We arrived at a series of theoretical and numerical results establishing the existence of an unbridgeable gap between the two.

- Accurate registration of images is the most important and challenging aspect of multi-frame image restoration problems such as super-resolution. The accuracy of super-resolution algorithms is quite often limited by the ability to register a set of low-resolution images. The main challenge in registering such images is the presence of aliasing. We have analyzed the problem of *jointly* registering a set of aliased images and its relationship to super-resolution. We derived a statistically optimal approach to multi-frame registration which exploits the concept of variable projections to achieve very efficient algorithms. Finally, we demonstrated how the proposed algorithm offers accurate estimation under various conditions when standard approaches fail to provide sufficient accuracy for super-resolution.

- Many existing techniques for image restoration can be expressed in terms of minimizing a particular cost function. Iterative regularization methods are a novel variation on this theme where the cost

function is not fixed, but rather refined iteratively at each step. This provides an unprecedented degree of control over the tradeoff between the bias and variance of the image estimate, which can result in improved overall estimation error. This useful property, along with the provable convergence properties of the sequence of estimates produced by these iterative regularization methods lend themselves to a variety of useful applications. We introduced a general set of iterative regularization methods, derived some of their fundamental properties and applications, which include denoising and deconvolution.

- *Kernel regression* is an effective tool for a variety of image processing tasks such as denoising and interpolation. We extended the use of kernel regression for deblurring applications. In some earlier examples in the literature, such non-parametric deblurring was sub-optimally performed in two sequential steps, namely, denoising followed by deblurring. In contrast, our optimal solution jointly denoises and deblurs images. The proposed algorithm takes advantage of an effective and novel image prior that generalizes some of the most popular regularization techniques in the literature. Experimental results demonstrated state of the art deblurring.

4. Personnel Supported

Peyman Milanfar, PI

Graduate Students Supported:

- Dirk Robinson (Ph.D.)
- Morteza Shahram (Ph.D.)
- Michael Charest (M.S.)
- Hiroyuki Takeda (Ph.D. ongoing)
- HaeJong Seo (Ph.D ongoing)
- Priyam Chatterjee (Ph.D. ongoing)

5. Technical Publications

Journal Publications

1. H. Takeda, S. Farsiu, P. Milanfar, “Deblurring Using Regularized Locally-Adaptive Kernel Regression”, IEEE Transactions on Image Processing, vol. 17, no. 4, pp. 550-563, Apr. 2008

2. L. Duponchel, P. Milanfar, C. Ruckebusch, and J.P Huvenne, “Super-resolution and Raman Chemical Imaging: From Multiple Low Resolution Images to a High Resolution Image”, Analytica Chimica Acta, 607 (2008) pp. 168–175

3. S. Farsiu, J. Christofferson, B. Eriksson, P. Milanfar, B. Friedlander, A. Shakouri, R. Nowak, “Statistical Detection and Imaging of Objects Hidden in Turbid Media Using Ballistic Photons”, Applied Optics, vol. 46, no. 23, pp. 5805-5822, August 2007

4. M. Charest, P. Milanfar, “On Iterative Regularization and Its Application”, IEEE Trans. on Circuits and Systems for Video Technology, vol. 18, no. 3, pp. 406-411, March 2008

5. X. Wang, S. Farsiu, P. Milanfar, and A. Shakouri, “Power Trace: An Efficient Method for Extracting the Power Dissipation Profile in an IC Chip from Its Temperature Map”, submitted to IEEE Trans. On Components and Packaging Technologies, June 2007

6. Poonawala, P. Milanfar, “A Pixel-Based Regularization Approach to Inverse Lithography”, Microelectronic Engineering, 84 (2007) pp. 2837–2852

7. D. Robinson, S. Farsiu, P. Milanfar, “Optimal Registration of Aliased Images Using Variable Projection with Applications to Superresolution”, Invited paper, The Computer Journal, April 2007; doi: 10.1093/comjnl/bxm007

8. M. Elad, P. Milanfar, R. Rubinstein, “Analysis versus Synthesis in Signal Priors”, Inverse Problems 23 (2007) pp. 947-968.

9. Poonawala, P. Milanfar, “Mask Design For Optical Microlithography—An Inverse Imaging Problem”, IEEE Trans. on Image Processing, vol. 16, no. 3, pp. 774-788, March 2007.

10. H. Takeda, S. Farsiu, and P. Milanfar, “Kernel Regression for Image Processing and Reconstruction”, IEEE Trans. on Image Processing, vol. 16, no. 2, pp. 349-366, February 2007.

11. S. Farsiu, M. Elad, and P. Milanfar, “Video-to-Video Dynamic Superresolution for Grayscale and Color Sequences ”, EURASIP Journal of Applied Signal Processing, Special Issue on Superresolution Imaging, Volume 2006, Article ID 61859, Pages 1-15.

12. M. Shahram, and P. Milanfar, “Statistical and Information-Theoretic Analysis of Resolution in Imaging”, IEEE Transactions on Information Theory, vol. 52, no. 8, pp. 3411-3427, August 2006.

13. D. Robinson, and P. Milanfar, “Statistical Performance Analysis of Super-resolution”, IEEE Transactions on Image Processing, Vol. 15, no. 6, pp. 1413-1428, June 2006.

14. R.J. Gardner, M. Kiderlen, and P. Milanfar, “Convergence of algorithms for reconstructing convex bodies and directional measures”, The Annals of Statistics, vol. 34, no. 3, pp. 1331-1374, June 2006.

15. A. Poonawala, P. Milanfar, R. Gardner, “Shape Estimation from Support and Diameter Functions”, Journal of Mathematical Imaging and Vision 24: pp. 229-244, March 2006.

16. S. Farsiu, M. Elad, and P. Milanfar, “Multi-Frame Demosaicing and Super-Resolution of Color Images”, IEEE Trans. on Image Processing, vol. 15, no. 1, pp. 141-159, January 2006.

17. M. Shahram, and P. Milanfar, “Local Detectors for High-Resolution Spectral Analysis: Algorithms and Performance”, Digital Signal Processing, vol. 15, pp. 305-316, 2005.

18. D. Robinson, and P. Milanfar, “Bias Minimizing Filter Design for Gradient-Based Image Registration”, Invited Paper, Signal Processing: Image Communication, Volume 20, Issue 6 (Special Issue on Advanced Aspects of Motion Estimation), pp. 554-568, July 2005.

19. M. Shahram, and P. Milanfar, “On the Resolvability of Sinusoids with Nearby Frequencies in the Presence of Noise”, IEEE Transactions on Signal Processing, vol. 53, no. 7, pp. 2579-2588, July 2005.

20. J. Tsaig, M. Elad, P. Milanfar, and G. Golub, “Variable projection for near-optimal filtering in low bit-rate block coders”, IEEE Transactions on Circuits and Systems for Video Technology, vol. 15, no. 1, pp. 154-160, January 2005.

21. S. Farsiu, D. Robinson, M. Elad, and P. Milanfar, “Advances and Challenges in Super-Resolution”, Invited Paper, International Journal of Imaging Systems and Technology, Special Issue on High Resolution Image Reconstruction, vol. 14, no. 2, pp. 47-57, 2004.

22. S. Farsiu, D. Robinson, M. Elad, and P. Milanfar, “Fast and Robust Multi-frame Super-resolution”, IEEE Transactions on Image Processing, vol. 13, no. 10, pp. 1327-1344, October 2004.

23. G. Boutry, M. Elad, G. Golub, and P. Milanfar, “The Generalized Eigenvalue Problem for Non-Square Pencils Using A Minimal Perturbation Approach”, SIAM Journal On Matrix Analysis and Applications, vol. 27, no. 2, pp. 582-601, 2005.

24. R. Cosgrove, P. Milanfar, and J. Kositsky, “Trained Detection of Buried Mines in SAR Images via the Deflection Optimal Criterion”, IEEE Transactions on Geoscience and Remote Sensing, vol. 42, no. 11, pp. 2569-2575, November 2004.

25. D. Robinson, and P. Milanfar, “Fundamental Performance Limits in Image Registration”, IEEE Transactions on Image Processing, vol. 13, no. 9, pp. 1185-1199, September 2004.

26. M. Elad, P. Milanfar, G.H. Golub, “Shape From Moments—An Estimation Theory Perspective”, IEEE Transactions on Signal Processing, vol. 52, no. 7, pp. 1814-1829, July 2004.

27. M. Shahram, and P. Milanfar, “Imaging Below the Diffraction Limit: A Statistical Analysis”, IEEE Transactions on Image Processing, vol. 13, no. 5, pp. 677-689, May 2004.

Reviewed Conference Proceedings

1. H. Seo, and P. Milanfar, “Video Denoising Using Higher Order Optimal Space-Time Adaptation”, Proceedings of IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP), pp.1249-1252, Las Vegas, NV, March 2008.

2. P. Chatterjee, and P. Milanfar, “A Generalization of Non-Local Means via Kernel Regression”, Proc. of the SPIE Conf. on Computational Imaging, San Jose, January 2008.

3. H. Takeda, H. Seo, P. Milanfar, “Statistical Approaches to Quality Assessment for Image Restoration”, Invited paper in Proceedings of the International Conference on Consumer Electronics, Las Vegas, NV, January 2008.

4. H. Seo, P. Chatterjee, H. Takeda, P. Milanfar, “A Comparison of Some State of the Art Image Denoising Methods”, Proceedings of the 41st Asilomar Conference on Signals, Systems, and Computers, Pacific Grove, CA, November 2007.

5. D. Robinson, S. Farsiu, J. Lo, P. Milanfar, C.A. Toth, “Efficient Registration of Aliased X-Ray Images”, Proceedings of the 41st Asilomar Conference on Signals, Systems, and Computers, Pacific Grove, CA, November 2007.

6. S. Farsiu, and P. Milanfar, “Multi-Scale Statistical Detection and Ballistic Imaging Through Turbid Media”, Proc. of the IEEE International Conference on Image Processing (ICIP), San Antonio, TX, September 2007.

7. X. Wang, A. Shakouri, S. Farsiu and P. Milanfar, “Extraction of Power Dissipation Profile in an IC Chip From Temperature Map”, Proc. of 23rd Semiconductor Thermal Measurement, Modeling, and Management (SemiTherm) Symposium, San Jose, CA, March 2007.

8. A. Poonawala, Y. Borodovsky, and P. Milanfar, “ILT for Double Exposure Lithography with Conventional and Novel Materials”, Proceedings of the SPIE Advanced Lithography Symposium, February 2007.

9. H. Takeda, S. Farsiu, and P. Milanfar, “Higher Order Bilateral Filters and Their Properties”, Proc. of the SPIE Conf. on Computational Imaging, San Jose, January 2007.

10. H. Takeda, S. Farsiu, and P. Milanfar, “Regularized Kernel Regression for Image Deblurring”, Proceedings of the 40th Asilomar Conference on Signals, Systems, and Computers, Pacific Grove, CA, November 2006.

11. H. Takeda, S. Farsiu, P. Milanfar, “Robust Kernel Regression for Restoration and Reconstruction of Images from Sparse, Noisy Data”, Proc. of the International Conference on Image Processing, Atlanta, GA, October 2006.

12. H. Takeda, S. Farsiu, J. Christou, P. Milanfar, “Super-Drizzle: Applications of Adaptive Kernel Regression in Astronomical Imaging”, Advanced Maui Optical and Space Surveillance (AMOS) Technologies Conference, September 2006.

13. M. Elad, P. Milanfar, R. Rubinstein, “Analysis versus synthesis in signal priors”, EUSIPCO, Florence, Italy, September 4-8, 2006.

14. M. Charest, M. Elad, P. Milanfar, “A General Iterative Regularization Framework For Image Denoising”, Proc. of the 40th Conference on Information Sciences and Systems, Princeton, NJ, March 2006.

15. A. Poonawala, and P. Milanfar, “OPC and PSM design using inverse lithography: A non-linear optimization approach”, Proc. of the SPIE Conference on Optical Microlithography XIX, San Jose, February 2006.

16. D. Odom, and P. Milanfar, “Modeling Multiscale Differential Pixel Statistics”, Proc. of the SPIE Conf. on Computational Imaging, San Jose, January 2006.

17. S. Farsiu, M. Elad, and P. Milanfar, “A Practical Approach to Super-Resolution”, Invited paper, Proc. of the SPIE Conf. on Visual Communications and Image Processing, San Jose, January 2006.

18. H. Takeda, S. Farsiu, and P. Milanfar, “Image Denoising by Adaptive Kernel Regression”, Proceedings of the 39th Asilomar Conference on Signals, Systems, and Computers, Pacific Grove, CA, November 2005.

19. S. Farsiu, M. Elad, P. Milanfar, “Constrained, Globally Optimal, Multi-frame Motion Estimation”, Proc. of the 2005 IEEE Workshop on Statistical Signal Processing, Bordeaux, France, July 2005.

20. P. Milanfar, “Resolution and Its Enhancement in Imaging” (Extended abstract), Invited Talk, Optical Society of America Topical Meeting on Signal Recovery and Synthesis, Charlotte, North Carolina, June 2005.

21. A. Poonawala, and P. Milanfar, “Prewarping Techniques in Imaging: Applications to Nanotechnology and Biotechnology”, Proceedings of SPIE Vol. 5674, SPIE Electronic Imaging, Conference on Computational Imaging III, San Jose, CA, January 2005.

22. L. Zimet, M. Shahram, P. Milanfar, “An Adaptive Framework for Image and Video Sensing”, Proceedings of SPIE Vol. 5678, SPIE Electronic Imaging, Conference on Digital Photography, San Jose, CA, January 2005.

23. M. Shahram, and P. Milanfar, “Improved Spectral Analysis of Nearby Tones Using Local Detectors” (Won best student paper award), Proceedings of the 2005 International Conference on Acoustic, Speech, and Signal Processing, Philadelphia, Pennsylvania, March 2005.

24. D. Robinson, and P. Milanfar, “Statistical Performance Analysis of Superresolution Image Reconstruction”, Proceedings of the 38th Asilomar Conference on Signals, Systems, and Computers, Pacific Grove, CA, November 2004.

25. S. Farsiu, D. Robinson, M. Elad, and P Milanfar, “Dynamic Demosaicing and Color Super-Resolution of Video Sequences”, Proceedings of SPIE Conference on Image Reconstruction from Incomplete Data III - Volume 5562, October 2004.

26. S. Farsiu, M. Elad, P. Milanfar, “Multi-Frame Demosaicing and Super-Resolution from Under-Sampled Color Images”, Proceedings of the SPIE Conference on Computational Imaging, Jan. 18-22, 2004, San Jose, CA.

6. Interactions/Transitions

The PI has presented 22 invited talks at forums around the world during the course of the project, as listed below.

Invited Speaker, U.C. Berkeley Electrical Engineering and Computer Science Department

Invited Speaker, Applied Mathematics Group, University of California, Davis

Invited Speaker, ARO Workshop on Information Theoretic Imaging, Huntsville, AL,

Invited Speaker, Xerox Palo Alto Research Center, Palo Alto, CA,

Invited Speaker, DARPA Adaptive Sensing and Waveform Design, Atlanta, GA,

Invited Speaker, International Conference on Super-resolution Imaging, Hong Kong,

Invited Speaker, AFOSR Signal Processing Program Review, Raleigh, NC,

Invited Speaker, AFRL/AFOSR ATR MURI Workshop, Dayton, OH,

Invited Speaker, OSA Topical Meeting on Signal Recovery and Synthesis, Charlotte, NC,

Invited Speaker, Department of Biophysics and Biochemistry, UC San Francisco, CA,

Invited Speaker, SPIE Conference on Video Coding and Image Processing, San Jose, CA

Invited Speaker, Directorate of Science and Technology, The Central Intelligence Agency

Invited Speaker, Air Force Office of Scientific Research TCATS Workshop, Tucson, AZ

Invited Speaker, DARPA Waveforms for Active Sensing Workshop, Portland, OR

Invited Speaker, European Signal Processing Conference, Florence, Italy

Invited Speaker, SIAM Conference on Imaging Science, Minneapolis, MN

Invited Speaker, Redwood Neuroscience Institute, Menlo Park, CA

Invited Speaker, Department of Mathematics, University of California, Davis

Invited Speaker, Conference on Applied Inverse Problems, Vancouver, BC, Canada

Invited Speaker, AFOSR Sensing Program Review, Harvard Univ., Cambridge, MA

Invited Speaker, SENSIP Center, Arizona State University, Tempe, AZ

Invited Speaker, Center for Advanced Signal and Image Sciences, Lawrence Livermore National Labs

6.1 Transitions

The results obtained in the course of this program had the following concrete effects on our research program and the state of the art in general.

Two PhD and one MS student were supported through graduation, contributing significant knowledge to the state of the art. These students have since taken up employment at research institutes, and government research laboratories.

Another important contribution of the program was that our work in the development of nonparametric statistical procedures led to a new program with the AFOSR where these ideas are being examined in far more detail and applied to numerous new directions. Ina real sense, the value of this program was not only what it produced in terms of intellectual output, but also in terms of the vast array of new doors it has opened for future research directions.

A third important outcome of this program was the technology transferred to the startup company MotionDSP.com, which was mentioned in last year's report. This startup company has received significant press attention, and has been extended financial support by In-Q-Tel, which is the independent investment arm of the Central Intelligence Agency. As such, we have had the privilege of observing the technology developed under this program being successfully transitioned into a real and promising business venture which has attracted the attention of both the commercial imaging market, and the intelligence community.

In addition, the non-commercial, research software package for super-resolution and kernel regression developed at UC continues to be adopted by government agencies and university research groups alike. Indeed, more than 150 research institutions around the world (both academic and government) have adopted our software packages for teaching and research purposes. Below we list a small sample of the these organizations.

- Dr. Hui-Chuan Wu
  The Central Intelligence Agency
  Directorate of Science and Technology
  McLean, VA

- Dr. Christine Edwards
  The National Security Agency
  Fort Mead, MD

- Dr. Todd Jenkins
  Air Force Research Labs
  Wright Patterson Air Force Base, OH

- Dr. Frank Kuehnel
  NASA, Ames Research Center
  Mountain View, CA

- Dr. Alan C. Schultz
  Navy Center for Applied Research in Artificial Intelligence
  Naval Research Laboratory
  Washington, D.C.

- Dr. Onur Eroglu
  Media Center, Communications Faculty
  Eastern Mediterranean University, Turkey

- Martin Ugander, MD, PhD
  Cardiac MRI Research Group
  Dept of Clinical Physiology
  Lund University Hospital, Lund, Sweden

- Prof. Frank Canters
  Department of Geography
  Vrije Universiteit Brussel
  Pleinlaan 2, B 1050 Brussel

- Prof. Serge Belongie
  University of California, San Diego
  Department of Computer Science & Engineering

- Yuichi Motai, Ph.D.
  Assistant Professor of Electrical and Computer Engineering,
  College of Engineering and Mathematical Sciences,
  University of Vermont
  Burlington, VT

- Giovanni Magenes
  Professor of Biomedical Signal Processing
  Dipartimento di Informatica e SIstemistica
  Univesità di Pavia, Italy

- Prof. Rae-Hong Park
  Dept. of Electronic Engineering
  Sogang University
  Seoul, Korea

- Dr David Brown
  Director, Institute of Industrial Research
  University of Portsmouth
  Portsmouth, United Kingdom

- Prof. Sergio Carrato
  IPL, DEEI, University of Trieste
  Trieste, Italy

- Dr N P Costen
  Department of Computing and Mathematics
  Manchester Metropolitan University
  Manchester, UK

- Prof. Yoonsuck Choe
  Department of Computer Science
  Texas A&M University
  Brain Networks Laboratory
  College Station, TX

- Prof. Anoop M. Namboodiri
  International Institute of Information Technology
  Hyderbad, India
- Dr. Dirk Vandermeulen
  ESAT/PSI Medical Image Computing
  Katholiek Universiteit Leuven
  Belgium

- Professor Edward Vrscay
  Deparment of Applied Mathematics
  University of Waterloo
  Waterloo, Ontario, Canada

- Rob Thomas
  Computer Science Department
  University of Bristol

Bristol, UK

- Dr. Lorenzo F. Leon
  Chilean Institute for Agricultural Research
  Chile

- Dr. Widhyakorn Asdornwised
  Department of Electrical Engineering
  Chulalongkorn University
  Bangkok, THAILAND

- Prof. David Malah
  Dept of Electrical Engineering
  Technion, Israel Institute of Technology
  Haifa, Israel

- Prof. Christian Winter
  Chair of Information Technology
  University of Erlangen, Germany

- Dr. Fatih Koroglu
  Institute of Electronics, Communication, and Information Technology
  Queens University
  Belfast, Ireland

- Professor Gaetano Saitta
  Faculty of Engineering
  Messina University
  Messina, Italy

- Prof. Erol Seke
  Dept. of Electrical and Electronics Engineering
  Osmangazi University
  Turkey

- Prof. Jae Ho Kim
  Department of Electronics Engineering
  Pusan National University
  Pusan, South Korea

- Prof. Jens-Reiner Ohm
  Aachen University (RWTH)
  Institut fuer Nachrichtentechnik
  Aachen, Germany

- Prof. Jayaram Udupa
  Chief of Medical Imaging
  Department of Radiology
  University of Pennsylvania

- Prof.Joel Hancq
  Faculté Polytechnique de Mons,
  Belgium

- Prof. Maria Perrou
  Electrical and Electronics Dept.
  Imperial College
  London, England

- Dr. Igor Carron
  Spacecraft Technology Center
  Texas A&M University
  College Station, TX, 77843-311

- Dr. Nicholas Besser
  Johns Hopkins University
  Applied Physics Laboratory
  Laurel, MD

- Dr. Mark Pickering
  Australian Defense Forces Academy
  University of New South Wales, Australia

- Professor Alex Zettl
  Department of Physics
  UC Berkeley, Berkeley, CA

- Professor Chiraz Ben Abdelkader
  Computer Science Department
  American University of Beirut, Lebanon

- Professor Ja-Lin Wu
  Computer and Information Science Department
  National Technical University of Taiwan

- Professor Pedro Carballo
  IUMA
  University of Las Palmas, Spain

- Dr. Yi Liu
  CSIRO Goverment Laboratories
  New South Wales, Australia

- Dr. Ludovic Duponchel
  CNRS, Laboratory for Spectroscopy
  University of Science and Technology,
  Lille, France

- Professor Truong Nguyen
  ECE Department
  University of California, San Diego

- Professor William Fitzgerald
  Department of Engineering
  Cambridge University, UK

- Prof. Vasillis Anastassopoulos
  Department of Physics
  University of Patras, Greece

- Professor Alan Yuille
  Department of Statistics and Computer Science
  University of California, Los Angeles

- Professor Lucas van Vliet
  Technical University of Delft, Netherlands

- Professor Jing Zhongliang
  Institute of Aerospace Science and Technology
  Shanghai Jiaotong University, China

- Professor Bir Bhanu
  Department of EE/CS
  University of California, Riverside

- Professor Byung-Guk Kim
  Inha University, South Korea

- Professor Wenkai Lu
  Tsinghua University
  Beijing, China

- Professor Tele Tan
  Curtin University
  Betley, Australia

- Dr. Klaus Tempfli
  Department of Earth Observation Sciences
  ITC Institute, Holland

- Professor Edwin Wang
  Department of Radiology
  New York University, NY

- Professor Bart ter Har Roomeny
  Department of Biomedical Engineering
  Eindhoven University, Netherlands

- Professor Stephen Reichenbach
  Computer Science Department
  University of Nebraska

- Professor James McGrath
  Biomedical Engineering Department
  University of Rochester

- Professor Rafael Molina
  Computer Science Department
  University of Granada, Spain

- Professor Aggelos Katsaggelos
  ECE Department
  Northwestern University, IL

- Prof. Stephane Mallat
  Centre de Mathematiques Appliquees
  Ecole Polytechnique
  Paris, France

- Prof. Martin Vetterli
  Audiovisual Communications Laboratory
  Ecole Polytechnique Federale de Lausanne
  (Swiss Federal Institute of Technology)

- Prof. Shahriar Negahdaripour
  ECE Department
  University of Miami
  Miami, FL

- Prof. Xin Li
  Computer Science and Electrical Engineering
  University of West Virginia
  Morgantown, WV

- Prof. Michael Elad
  Computer Science Department
  Technion, Israel Institute of Technology
  Haifa, Israel

- Prof. Rafael Garcia
  Dept. of Electronics, Informatics and Automation,
  University of Girona,
  Girona, Spain

- Prof. Donald Bailey
  Institute of Information Sciences and Technology
  Massey University
  Palmerston North, New Zealand

- Dr. Maria Jesus Gutierrez
  Instituto Nacional De Tecnica Aerospacial
  (Earth Observation Department)
  Spanish Ministry of Defense
  Torrejon de Ardoz, Spain

- Professor Subhasis Chaudhuri
  Vision and Image Processing Lab
  Electrical Engineering Department
  Indian Institute of Technology
  Bombay, India

- Prof. Prem K Kalra
  Head , EE Department
  Indian Institute of Technology,
  Kanpur, India

- Prof. Sarp Erturk
  Electronics and Telecommunications Engineering Dept.
  University of Kocaeli, Turkey

- J M Blackledge,
  Professor of Digital Signal Processing and Communications Technology
  Applied Signal Processing Research Group,
  Department of Electronic and Electrical Engineering
  Faculty of Engineering, Loughborough University,
  Leicestershire, UK